

FAILOVER IN CELLULAR AUTOMATA

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Abstract

A cellular automata (CA) configuration is constructed that exhibits emergent failover. The configuration is based on standard Game of Life rules. Gliders and glider-guns form the core messaging structure in the configuration. The blinker is represented as the basic computational unit, and it is shown how it can be recreated in case of a failure. Stateless failover using primary-backup mechanism is demonstrated. The details of the CA components used in the configuration and its working are described, and a simulation of the complete configuration is also presented.

Keywords: failover; cellular automata; Game of Life; emergence

1 Introduction

Cellular automata (CA) have been widely used to model complex systems. CA succinctly model the self-organizing and emergent properties of complex systems. Together with their parallelized structure, Cellular automata make one of most suitable models for complex systems. Simple CA constructions often yield collective complex behaviors [17].

In addition to modeling complex systems, CA themselves can be considered as computational units. Such consideration comes under the category of non-standard models of computation and is called Collision Based Computing [11]. Various logic functions such as NOT, AND and OR have been constructed in the “Game of Life” CA. The Game of Life (GOL) [2] is a popular CA which has yielded many complicated patterns based on its simple set of rules. Many complex patterns arise out of some of the basic patterns that occur in the GOL. We use some of the basic patterns such as gliders, blinkers (oscillators), still-life (invariants) and glider-guns [2] that occur in the GOL to set up our configuration. Various circuits can be built up based on the logical functions that forms one of the techniques to demonstrate universal computation [11]. Universal Turing machines have also been simulated in many different CAs [4, 5] and in particular the GOL also. Gliders and glider-guns form the key patterns

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that are used in the universal Turing machine in the GOL. From the computing perspective of our construction we represent a blinker as our basic computational unit. It can be viewed as two-bit counter and we show how its computation can continue in case of failure.

In this paper, we present a basic model for failover as a complex system behavior. Failover is a widely used distributed-system concept used to make systems highly available. Many different techniques of achieving failover have been discussed [14, 6]. Failover is one of the techniques to make a system fault tolerant, which is a system that continues to operate even in case of certain faults. Failover techniques involve the use of redundant components [7, 13]. We achieve failover in CA by making use of redundant CA components. We use the primary-backup approach [1, 3] to implement failover. In this approach, a standby module takes over the active module when there is a failure in the active module. Usually the active module is called the *primary* and the standby is called the *backup*. This ensures that the system as a whole is available even if there are failures in some of its components. The primary and the backup exchange messages between them which are usually called the *heartbeat* (which may colloquially be described as “I’m alive”) messages. Initially the primary system is in the active state and performs the required tasks. It also sends the heartbeat message to the backup system. The backup is usually in a passive state and is not involved in the actual work. If the primary module fails then the backup does not receive any heartbeat messages from the primary, and moves from its standby state and takes over the work.

Failover is mainly of two types:

- *Stateless* failover: In this type of failover, the backup does not have any state information of the primary and in case of failure, it restarts the computation as if newly started.
- *Stateful* failover: In this type of failover, the backup maintains the state information of the primary and in case of a failure, it resumes from this state.

Our discussion in this paper restricts to stateless failover. Also, we assume the failure of complete component or module rather than failure of individual cells. Our model is based on fail-stop in which the system as a whole comes to a halt in case of failures. We also assume the presence of a global synchronization clock.

Section 2 gives a brief description of related work. In Section 3, we present the model for a failover in CA. Section 3.1 describes the different components used in our construction for the failover configuration. Section 4 gives the details of the failover construction and the simulation setup and working. We finally provide the conclusion in Section 5. The appendix section gives a description about CA and the basic GOL components used.

2 Related Work

Reliable computation with cellular automata involving probabilistic fault models have been studied in one-dimensional cellular automata [9]. Self-repairing constructions are used to deal with these faults. Synchronous systems, which require the existence of a fault-free global synchronization clock, are assumed. Asynchronous extensions of reliable computation have been done on two-dimensional cellular automata that perform computation with a probability of meeting reliability requirements [16]. Transient models of *fault tolerance in CA at high rates* have been studied and fault rate bounds have also been derived for these models [12].

Evolutionary algorithms have been applied to cellular automata to determine the complex global behavior they exhibit or to solve a particular problem. Various computational tasks such as density, synchronization, and random number generation have been demonstrated on non-uniform Cellular Automata employing genetic algorithms. In non-uniform CA, the interaction rules vary in different sections of the cellular space whereas in uniform CA there are uniform common rules for the complete cellular space. Fault-tolerant behavior under random faults have been studied in the non-uniform CA using evolutionary algorithms to perform computational tasks such as the density task and synchronization task [15].

3 CA Model for Failover

In this section, we describe our model for failover in CA (see Figure 1). We use some of the basic GOL patterns mentioned in the appendix and also some additional patterns. These form the building blocks for our failover configuration. To construct the failover configuration we need:

- Primary Module
- Backup Module
- Communication Mechanism
- Trigger for the Failover

In our configuration, the CA grid is divided into two logical sections. One of them forms the primary module and the other the backup module. These two sections are made up of similar components but they differ in their arrangement. The glider guns and the gliders together form the communication mechanism between the primary and the backup. The gliders also act as the trigger for the backup module in case of the failure of the primary.

Each section has a pair of glider guns and a blinker. The blinker in the primary is called the active blinker and in the backup is called a passive blinker. One of the glider guns is called the internal glider gun and the other the external

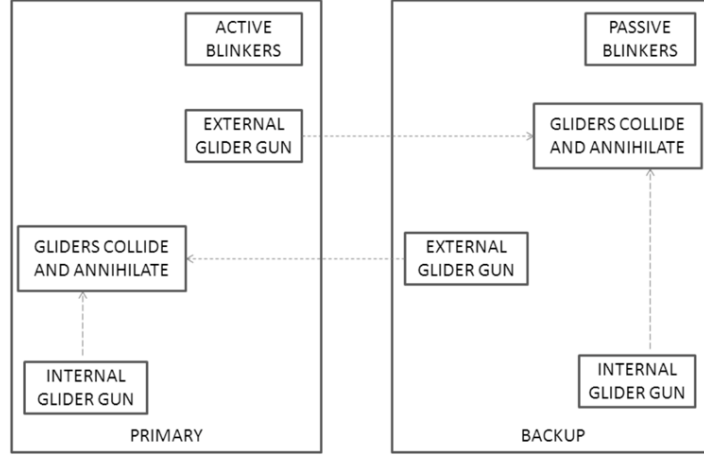


Figure 1: CA model for Failover

glider gun. The external glider gun of the primary communicates with the internal glider gun of the backup and vice versa. These essentially form the communication and trigger mechanism for the system. The specific details of each component are mentioned in the following subsection.

3.1 CA components in the model

Active Blinker: The blinker associated with the primary module is called the active blinker. It is a configuration where the cells oscillate between two different states.

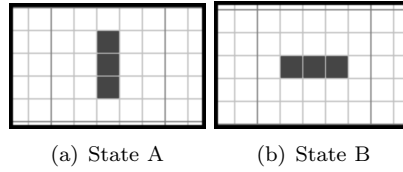


Figure 2: Blinker

Passive Blinker: It is a specific still-life configuration that transforms into a blinker when collided with by a glider. One of the passive blinkers we use is as shown in Figure 3(a).

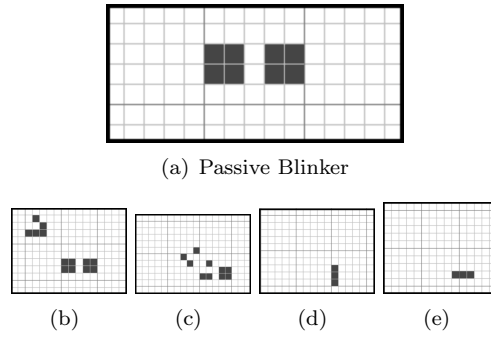


Figure 3: Collision of Passive Blinker with Glider

Glider Reflector: This configuration changes the angle of a glider by 90° . This configuration is also called as the *boat*. It destroys itself after the glider has been reflected and so is a one-time reflector. The working is as shown in Figure 4.

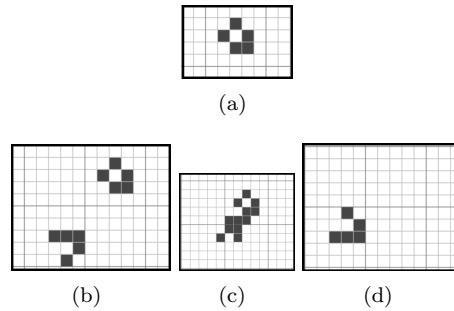


Figure 4: Glider reflected by 90°

P-92 Glider Gun [8]: It is similar to the Gosper Gun (appendix) except that it emits a glider every 92 generations.

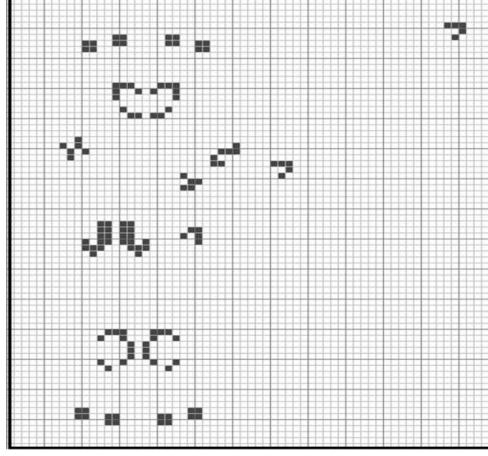


Figure 5: Period-92 Glider Gun

Collision between Gliders: When two gliders collide with each other at a specific angle, they annihilate. The working is as shown in Figure 6.

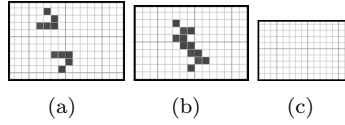


Figure 6: Annihilating Gliders

4 Simulation and Analysis

A complete setup for the configuration is as shown in Figure 8. The dimensions of the grid are 420×200 . The configuration is shown as a pair of two figures, one representing the left part and the other right part, but the complete configuration is to be interpreted as a concatenation of right part to left part as shown in Figure 7.

The grid is divided into two logical sections, namely, the primary and the backup. The primary contains a set of two P-92 glider guns 207 cells apart horizontally and 60 cells apart vertically. One of them acts as an external glider gun that emits gliders towards the backup and other an internal glider gun that emits gliders inside the logical section in the module. The horizontal distance is measured from the rightmost active cell of the internal glider gun to the leftmost active cell of the external glider gun. Similarly, the vertical distance is

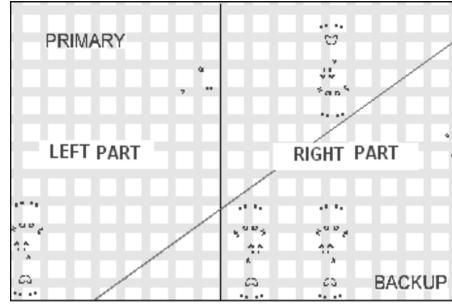
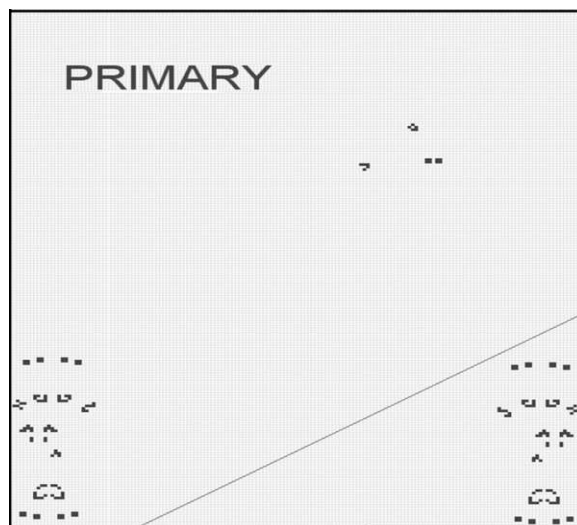


Figure 7: Configuration Figures Interpretation Helper

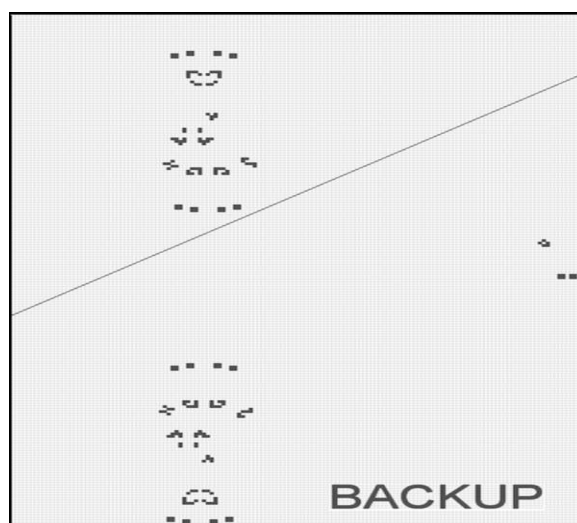
the distance from the topmost active cell of internal glider gun to the bottom-most active cell of the external glider gun. The glider reflector is placed at a location such that gliders of the internal glider gun may collide with it and get reflected by 90° . In addition to these, the primary also has a trigger glider. It is also placed such that it collides with reflector. A passive blinker is placed at a location such that it is at an angle suitable to be transformed into an active blinker when collided with by the reflected glider. The backup contains similar components as that of the primary but they are slightly different in their structures. The backup contains a set of two P-92 glider guns but these are 39 cells apart horizontally. In case of backup, the internal glider gun is translated one cell up compared to the external glider gun. It also contains a glider reflector and passive blinker placed at locations to get a similar effect as that mentioned for the primary. One important difference is that there is no input trigger glider in the backup.

Table 1: Interaction between different CA components

Component	Collides with Component	Result
Glider from Backup's Internal Glider Gun	Glider from Primary's External Glider Gun	Annihilation
Glider from Backup's Internal Glider Gun	–	Collision with Passive Blinker and transformation into Active Blinker
Input Glider	Passive Blinker	Transformation into Active Blinker
Glider	Boat	Change the direction of glider by 90°



(a)



(b)

Figure 8: Failover Configuration

The simulation has controls such as *KillPrimary*, *ResetBackup*, *Init* that aid in simulating the different conditions of the system.

- *Init*: This action sets the cells of the primary and backup sections to be in their initial configurations.
- *KillPrimary*: This action clears all the cells in the primary section of the grid. This action is used to bring down the primary module, i.e., to simulate a failure in the primary.
- *ResetBackup*: This action restores the cells of the backup to its standby state. The standby state is exactly same as that of the initial backup's state.

The system initially is brought up in a start state configuration. In this state, both blinkers are passive. When the system is started, the input trigger glider in the primary collides with glider-reflector and changes its direction by 90° . Now it collides with the passive blinker in the primary and transforms it into an active one. Meanwhile the communication mechanism of the gliders is also triggered to start. The glider from the primary's external glider gun is the heartbeat message sent to the backup and vice versa. The gliders from the external gun move to the backup section and collide with the gliders of the internal glider gun of the backup. As long as the gliders collide and annihilate, the backup may be said to infer that the primary is alive. There is a similar heartbeat message coming from the external glider gun which collides with primary's glider gun, so that the primary infers that backup is alive.

PrimaryDown: This condition is simulated by invoking the *KillPrimary* action. The cells of the primary section are cleared off. This is similar to bringing down the primary module. The configuration is as shown in Figure 9. In this case, there is no glider emitted from the external gun of the primary. Therefore the passive blinker in the backup module is triggered by its internal glider gun and becomes active. Now, the backup becomes the primary and continues functioning. The configuration is as shown in Figure 10.

ResetBackup: The backup is reset by invoking the *ResetBackup* action. The cells of the current backup section are set to the standby state. This action is invoked after primary has gone down and when the backup module has become the current primary.

When the failed primary module is brought back, it comes up in its start state which has a passive blinker. Now, this acts as a backup and continues the exchange of messages through the glider guns. The configuration is as shown in Figure 11.

In the failover configuration discussed here, in case of a primary failure, the backup waits until all the messages (gliders) that have been sent by the primary before it went down are received. The maximum time for the backup to come into action would be the (number of gliders present in the communication path times 92 generations) + number of generations required for the internal glider to collide with the passive blinker.

When the backup is reset, it is necessary that it is synchronized with the primary's external glider gun. If the glider guns are not synchronized, the gliders may not collide at the appropriate angles and therefore may not annihilate. The backup needs to be reset at any $(N \times 92)^{th}$ (where $N = 1, 2, 3, \dots$) generation for the communication mechanism to resume properly.

5 Conclusion

In this paper, we have shown that the real world distributed-system concept of failover can be modeled using cellular automata. We focused on stateless failover and constructed a cellular automata configuration that demonstrates failover using the standard game-of-life rules. The period-92 glider guns were used as the basic communication and trigger mechanism between the primary and backup. We represent blinkers as our basic computational units and show how the backup's passive blinker transforms into an active on failure of the primary module. We also showed that the backup, when reset, comes back as a hot standby and whole switching process of primary-backup can continue indefinitely as long as there is a single (primary) failure and the backup can be reset. A possible extension of this model would be to demonstrate a stateful failover in which case the primary and the backup would maintain state information and in case of a failure the backup takes over from where the primary module left off before going down. This construction can also find its use as a reusable component in larger complex configurations.

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A Cellular Automata

A Cellular Automaton is a discrete model of a collection of cells. The cells can take any of the states from a set of states. At every time t (sometimes called generation), the state of each cell is updated. The state of a cell depends on its current state and the state of its neighbors. These constitute the rules for the CA. The cells are usually rectangular although there are various other geometric shapes such as hexagonal as well. The cells can be arranged in n -dimensional space. The most commonly occurring CA are one, two and three-dimensional although higher dimensions also have been explored. We restrict our discussion here to 2-dimensional CA. The most popular CA so far has been the game of life (GOL) created by John Conway [2].

The game of life is a 2-dimensional rectangular array of cells and the cells can exist in either of the two states i.e. alive or dead. It is based on simple rules which can be represented as (new_life, over_population, under_population).

- A dead cell with exactly ‘new_life’ number of neighbors alive becomes alive in the next generation
- An alive cell with greater than ‘over_population’ number of neighbors or lesser than ‘under_population’ number of neighbors dies in the next generation.

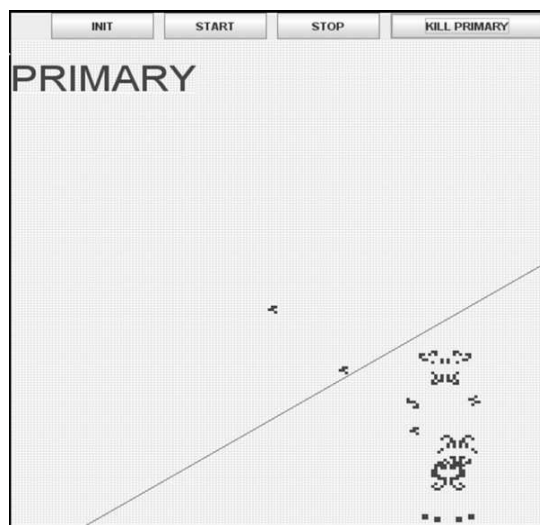
Conway’s game of life rule is given as (3, 3, 2). Many complex patterns have emerged out of this simple rule and many more are being discovered. The most commonly occurring patterns are described below

Still Life: It is a configuration where all the cells stay alive for all generations

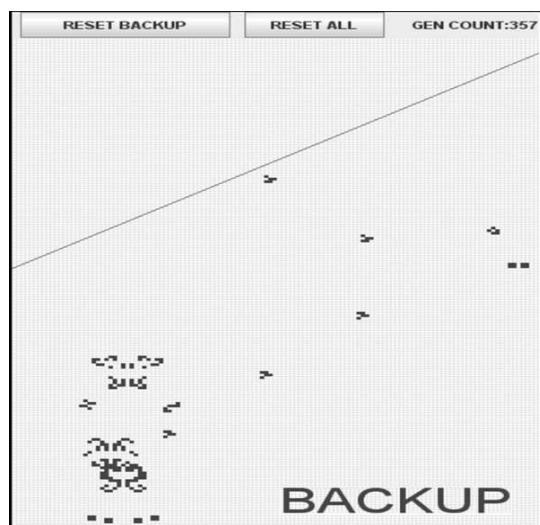
Blinker/Oscillator: It is a configuration where the cells oscillate between two different states.

Glider: It is a configuration which translates itself after a certain number of generations.

Glider gun: It is a configuration that constantly emits gliders. The first ever glider gun was discovered by Gosper [10]. It is a p30 glider gun that emits a glider for every 30 generations.

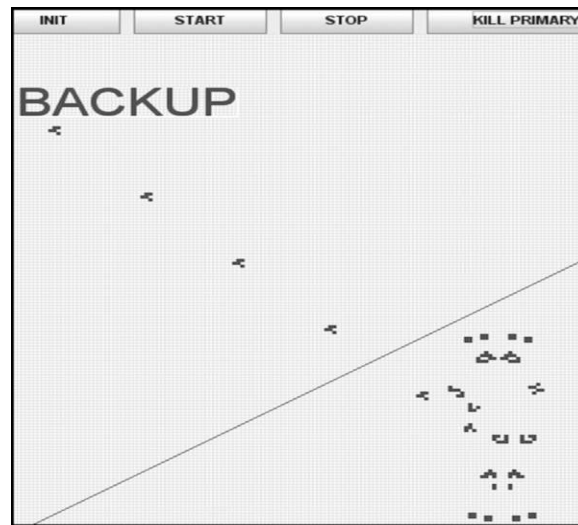


(a)

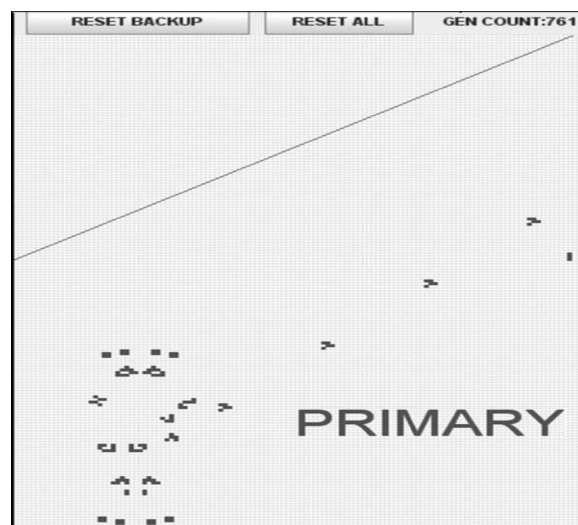


(b)

Figure 9: Primary Down and Before Backup becomes Primary

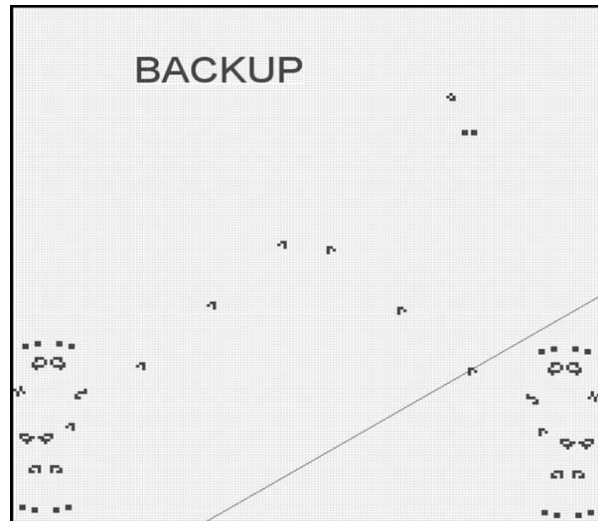


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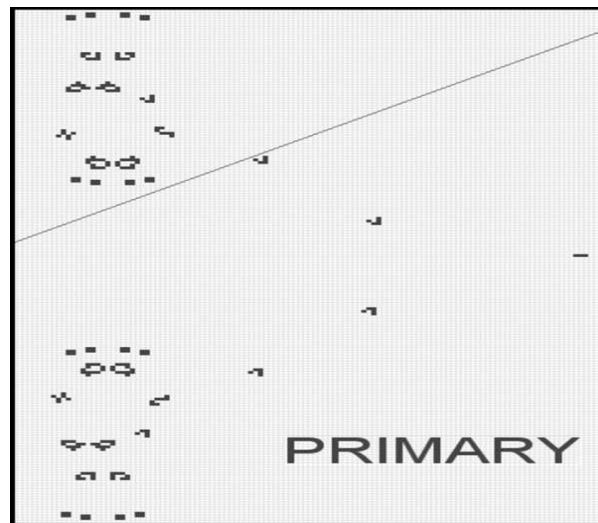


(b)

Figure 10: Primary Down and Backup becomes Primary



(a)



(b)

Figure 11: After Backup is Reset

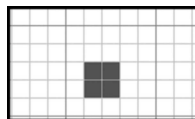


Figure 12: Still life

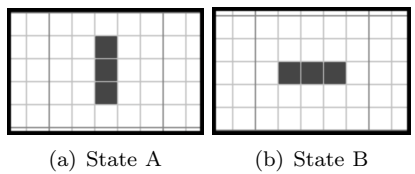


Figure 13: Blinker

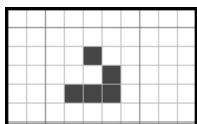


Figure 14: Glider

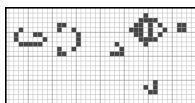


Figure 15: Gosper Gun